Interruption of patent ductus arteriosus in children: Robotically assisted versus videothoracoscopic surgery

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Objectives: If robotic surgery is to be widely used, the risks must be equivalent to those of standard techniques. This study analyzes the feasibility, safety, and efficiency of a robotically assisted technique for patent ductus arteriosus closure and compares the results with those of the videothoracoscopic technique.

Methods: During 2000, 56 children weighing 2.3 to 57 kg (mean, 12 kg) underwent surgical closure of a patent ductus arteriosus. They were distributed into 2 groups: 28 patients (group 1) underwent the videothoracoscopic technique, and 28 (group 2) underwent a robotically assisted (Zeus; Computer Motion, Inc, Goleta, Calif) approach. Operative and postoperative surgical data were studied.

Results: Operative time was significantly higher in the robotically assisted group. One conversion in videothoracoscopy was necessary, but no thoracotomy was required. Three persistent shunts were detected at postoperative echocardiography and were treated by means of application of a new clip with videothoracoscopy (1 in group 1 and 2 in group 2). No permanent laryngeal nerve injury and no hemorrhage were noted. The mean hospital stay was 3 days in both groups.

Conclusions: Robotically assisted closure of a patent ductus arteriosus is comparable with closure by means of the videothoracoscopic technique. However, it requires a longer operative time because of the increment in complexity.

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Significant advances in technology over the past decade have allowed the development of minimally invasive endoscopic operative techniques in a variety of surgical disciplines. Since 1991, we have performed 630 procedures for closure of a patent ductus arteriosus (PDA) using a videothoracoscopic approach. These endoscopic procedures have reduced cost, patient morbidity, and length of hospital stay. Recently, a new generation of surgical telemanipulation systems has helped to partially overcome the limitations of conventional endoscopic tools. These computer-enhanced instrumentation systems provide tremor filtering and motion scaling and allow dexterous manipulations in confined spaces through ports or trocards. The purpose of this study was to demonstrate the feasibility of PDA closure in children by using a robotically assisted surgical system and to compare the quality, safety, and results of this technique with those obtained by using the videothoracoscopic approach.

TABLE 1. Breakdown of the patients by age group

	Group 1 (n = 28): Videothoracoscopic	Group 2 (n = 28): Robotically assisted
Age <6 mo	10.7%	14%
Age 6–48 mo	67.8%	82%
Age >48 mo	21.4%	4%

Material and Methods

Patients

From January 1, 2000, to December 31, 2000, 60 children were referred to our institution for elective surgical PDA closure. Fifty-six were considered for the videothoracoscopic approach, including premature infants. Patients with previous thoracotomies were excluded, as were patients with a ductus of greater than 9 mm in diameter (transthoracic echocardiographic evaluation) or PDA complicated by endocarditis.

Children were distributed into 2 groups (Table 1). In group 1, 28 infants (age, 3 weeks-15 years; mean age, 33 months; weight, 2.3–57 kg; mean weight, 13.3 kg; sex ratio, 5:1 girls/boys) underwent the videothoracoscopic procedure. In group 2, 28 infants (age 2 months-5½ years; mean age, 20 months; weight, 3.2–22.5 kg; mean weight, 10.7 kg; sex ratio, 6:1 girls/boys) underwent a robotically assisted procedure.

Surgical Technique

Group 1. This technique has already been described by our team[1,2] and has not been changed since 1991.

After induction of general anesthesia and standard intubation, the patient is positioned as for a left posterolateral thoracotomy. The surgeon and the scrub nurse are on the left side of the patient, and the assistant is on the right. The monitor is placed on the right side of the patient, facing the surgeon. Instruments used for videothoracoscopy include an electrocautery hook, a clip applier, and three 60° angled hooks for lung retraction.

Two small incisions with a No. 11 blade are made in the left hemithorax: the first incision is made just posterior to the scapula in the third intercostal space for the videothoracoscope (4 mm in diameter) to be introduced through a 5-mm trocar. A second incision is performed in the fourth intercostal space underneath the angle of the scapula for the electrocautery hook to be introduced through a 5-mm trocar. Three 60° angled hooks of 1 mm in diameter are introduced directly through the third intercostal space in its middle part, just in front of the scapula, for lung retraction (Figure 1).

The upper lobe of the left lung is retracted inferomedially with 2 angled hooks, the PDA is identified, and the mediastinal pleura is opened with the electrocautery hook and retracted with the third angled hook. The PDA is dissected from the surrounding tissues, and the aorta is dissected at its junction with the PDA. The pericardium is dissected on the pulmonary side to protect the recurrent laryngeal nerve from any traumatic injury. The clip applier is then introduced without any trocar through the 10-mm access point in the fourth intercostal space. A first titanium clip (9 mm) is placed as distally as possible from the aortic junction on the pulmonary side of the PDA, and a second clip is applied on the aortic side. After visual confirmation that both clips are securely in place, the lung is inflated, and a 2-mm-diameter pleural suction catheter is placed before closure of the skin incisions with sutures.

Group 2. The Zeus System (Computer Motion, Inc, Goleta, Calif) includes 1 voice-controlled robotic arm (automated endoscope system for optimal positioning [AESOP]), 2 instrument positioners, 1 surgeon console, and 1 interface controller. The instruments and the videoscope are coupled to the robotic arm with adjustable magnetic couplers. The telemanipulation system and technical details have been described elsewhere.[3] For PDA closure, the voice-controlled robotic arm is positioned on the foot side on the left rail, and instrument positioners are installed on the head side on the left rail and the foot side on the right rail.

Preparation, installation of the patient, anesthesia, incisions, and introduction of instruments are the same as in group 1.

The videoscope is attached to the AESOP arm, the 2 first 60° angled hooks for lung retraction are held by the assistant, the third hook is connected to the left arm of the robot, and the electrocautery hook is held by the right arm of the robot. Once instruments are installed and connected to the robot, the surgeon leaves the table and moves to the console. Seated in front of the console, the surgeon works with 2 instruments: a hook retractor controlled with the right hand and an electrocautery hook controlled with the left hand. Using a foot-switch pedal, the tips of the instruments can be temporarily disconnected from the master handles, which can be repositioned in the working space to achieve the most convenient ergonomic position.

The whole dissection of the pleural reflection, of the aorta, and of the ductus is carried out from the console. When the ductus is completely dissected from the surrounding tissues, the surgeon goes back to the operating table and places the 2 clips in the same way as in group 1.

Postoperative Care

Color flow Doppler echocardiography is performed in the operating room or in the recovery room before extubation to assess the completeness of closure of the PDA. If a persistent shunt is noted, the patient is taken back immediately to the operating room for application of a new clip by means of videothoracoscopy. If complete interruption is obtained, the child is extubated and placed either in the intensive care unit (ICU) or in the pediatric ward according to his or her age and the possible previous symptoms of pulmonary hypertension. The pleural suction catheter is removed a few hours after extubation, a routine chest radiograph is obtained, and a transthoracic echocardiogram is done before the patient is discharged. All patients are then regularly followed up by the referring pediatric cardiologist on the 10th day after discharge and after 6 months.

Data Analysis

In both groups total operating room time, surgical procedure time, conversion for technical failure or surgical problems, and accidents of dissection were analyzed. The following postoperative data were analyzed: duration of ICU and hospital stay, continuance of persistent shunt, reoperation, temporary or permanent laryngeal nerve injury, chylothorax, pneumothorax, wound infections, hemorrhages, and blood transfusions.

This study was approved by the ethics committee of our institution, and informed consent was obtained from the parents of the patients.

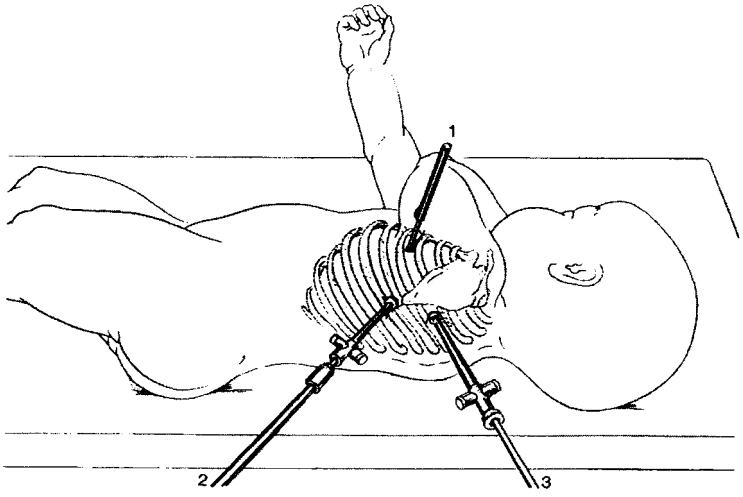

Figure 1. Position of the patient and setup of the various ports: *1*, angled hook retractor; *2*, electrocautery hook; *3*, camera.

TABLE 2. Operative data of patients undergoing PDA closure by means of the thoracoscopic approach versus robotically assisted videothoracoscopy

	Group 1: Videothoracoscopic	Group 2: Robotically assisted	*P* value
Operating room time (min)	83.52 (65-110)	162 (130-210)	<.01
Surgical procedure time (min)	24.24 (11-50)	49.9 (30-75)	<.01
Accident	0	0	
Conversion	0	1 in videothoracoscopy	

Results

Operative Data

The robotically assisted PDA closure procedure was completed in all 28 patients in group 2, except one. All operative data are listed in Table 2.

The total operating room and surgical procedure time was significantly higher in group 2. No conversion in thoracotomy was observed in any patient from either group. Because of poor exposition caused by insufficient lung retraction, it was necessary to convert to classical thoracoscopy in one patient of group 2. No accident or incident was observed in either group.

Postoperative Data

Postoperative data are listed in Table 3. There was no difference between the 2 groups in terms of ICU and hospital length of stay. In both groups the mean ICU stay was less than 6 hours, and the postoperative ventilation time was less than 2 hours.

Reversible laryngeal nerve injury was noted in one patient in each group. All of them had transient dysphonia and were followed in the department of otolaryngology.

A persisting shunt was observed in 3 patients (1 in group 1 and 2 in group 2). The 3 children were reoperated on the same day by means of the thoracoscopic approach. In all patients the persisting shunt was related to an incomplete dissection of the ductus and misplacement of the clips.

No residual shunt was noted at discharge. No chylothorax, no wound infection, and no hemorrhage were observed. One pneumothorax in group 1 required percutaneous drainage. No midterm complications, including recurrence of ductal shunting, were observed.

Discussion

In an effort to improve surgical skills and facilitate endoscopic surgery, computer-enhanced surgical robots have been developed. The term *robot* describes a heterogeneous group of machines used in a great variety of applications. Usually robots are designed to perform high-precision tasks repeatedly or to work in an environment not suitable for human beings. These devices are programmed to perform a certain task, which is then executed on command. Robots of this sort are used in orthopedic surgery and for image-guided neurosurgical navigation on the basis of the preoperative patient data set. In cardiac surgery the machine is required to improve the surgeon's skill and to increase the precision of endoscopic instruments through computer motion scaling and tremor elimination. The surgeon manipu-

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TABLE 3. Postoperative results in patients undergoing PDA closure by means of a thoracoscopic approach versus robotically assisted videothoracoscopy

	Group 1: Videothoracoscopic	Group 2: Robotically assisted	*P* value
ICU stay (d)	1	1	NS
Hospital stay (d)	3.07 (2-4)	3.0 (2-4)	NS
Persistent shunt	1	2	NS
Reintervention	1	2	NS
Residual shunt	0	0	NS
Permanent laryngeal nerve injury	0	0	NS
Chylothorax	0	0	NS
Pneumothorax	1	0	NS
Wound infection	0	0	NS
Hemorrhages	0	0	NS

NS, Not significant.

lates the system from a console, and his or her gestures are transmitted to the instruments by means of telemanipulation. Consequently, for the moment, these devices must be considered more as telemanipulators than robots. Telemanipulators are constantly controlled by an operator who works at an input device (master), while his commands or motions are executed remotely by the manipulator (slave).

The Zeus system (Computer Motion) used in this study is a master-slave telemanipulator, the modular units of which can be freely mounted on the operating table. The voice-activated robotic arm, AESOP, is used to guide a videoscope, which obeys simple 1- or 2-word commands.

In 1998, Carpentier and colleagues[4] performed the first robotic cardiac surgical procedures in adults, including an atrial septal defect closure and several mitral valve repairs. Recently, Mohr and associates[5] published their experience, in which they brought mitral valve surgery to a near-endoscopic procedure. In 1999, endoscopic robotic coronary operations were described.[6,7] Despite the elegance of the robotic technique, the authors insisted on the difficulty of achieving the dissection and the anastomosis.

The current study demonstrates that endoscopic PDA closure with robotically assisted instrumentation is technically feasible in children, even in low-weight babies. The dissection of the aorta, of the subclavian artery, and of the ductus can be safely achieved. Indeed, neither accident nor particular difficulties were observed in our experience. The exposure of the duct and lung retraction was obtained by using 2 angled hooks held by an assistant in the same way as in the videothoracoscopic technique. As a matter of fact, failure in exposition was the cause of the unique conversion to thoracoscopy in our experience.

Intraoperative data show that the operating room time and the surgical procedure duration were significantly higher in the robotic group, with the difference remaining constant throughout the whole experience and therefore regardless of the learning curve. This difference is not due to specific surgical difficulties but rather to the technical complexity of the robot placement. In this experience an engineer was present in the operating room during the procedure to take care of the possible technical failures and breakdowns. Despite our increasing experience and the permanent maintenance of the machine, technical flaws could not be totally eliminated.

Our experience was extremely useful because it allowed us to demonstrate that, after a learning period during which the exact position of the robotic tools had to be determined, the robotic arms could be installed and mobilized easily and safely and could perform all the maneuvers required by the surgical procedure. In addition, because no case of infection had been observed in this experience, we may state that those cumbersome tools can be safely decontaminated and protected and that their use does not increase the risk of infection.

In conclusion, our experience with the robotic approach for PAD interruption in children did not prove to be either superior or inferior to the videothoracoscopic technique used in our institution since 1991 in terms of safety, quality of outcome, and reduction of complication. It appears more complicated, demanding, and time-consuming and presently has no particular advantage over the regular technique. The next step will be to improve the technology to provide the robot with a certain degree of autonomy. This will be a real additional value in the performance of a certain surgical task.

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